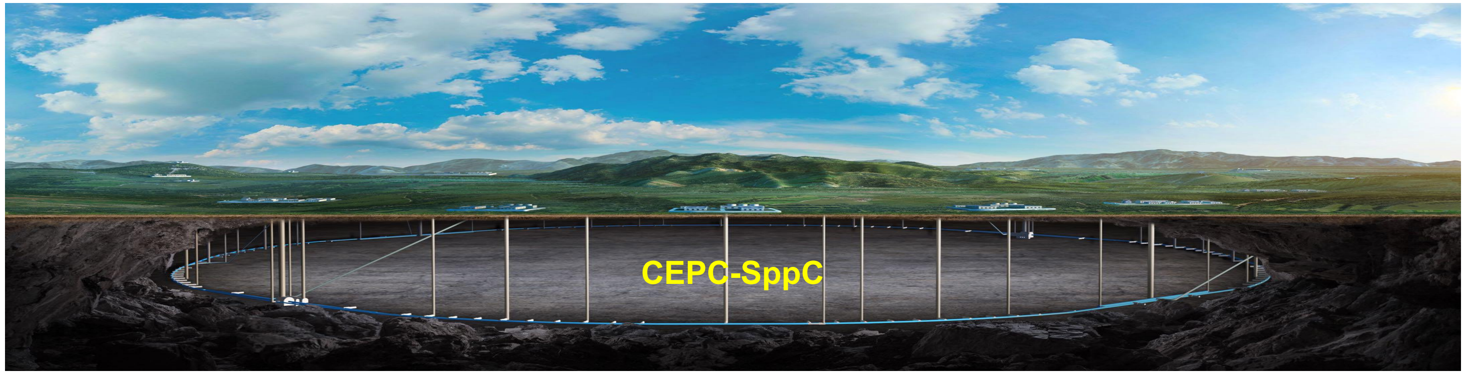
Staging of CEPC and SppC for High Energy Frontier

J. Gao

IHEP

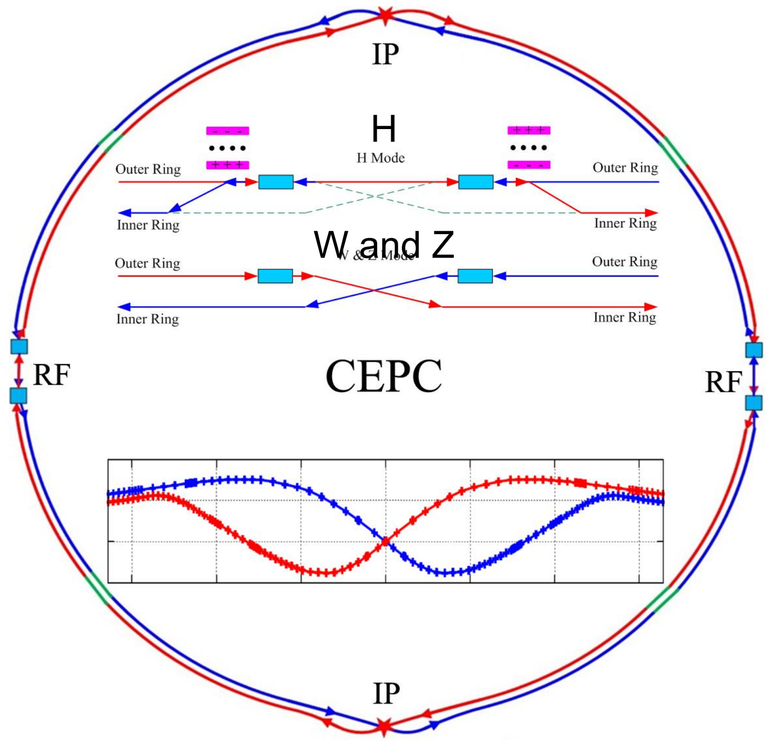
On behalf of CEPC-SppC Group



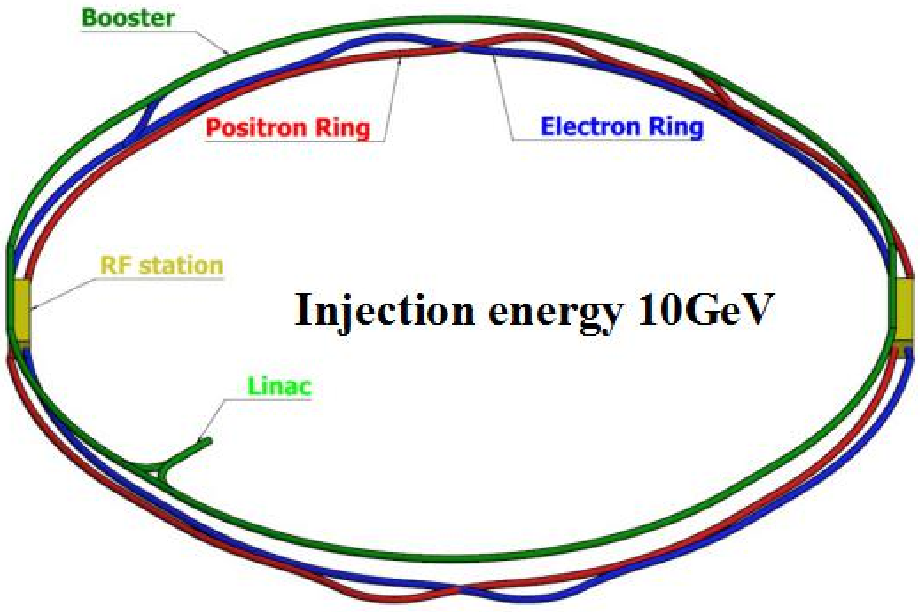
Snowmass Community Planning Meeting （CPM）, Oct. 6，2020

CEPC CDR Baseline Layout

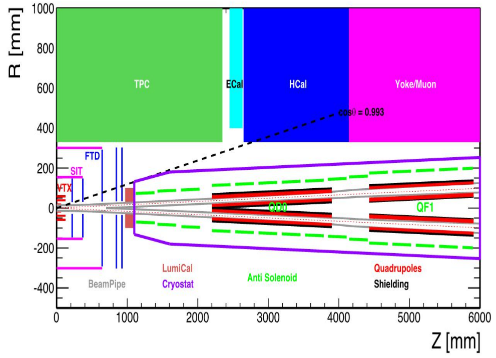
CEPC as a Higgs Factory： H, W, Z, followed by a SppC ~100TeV

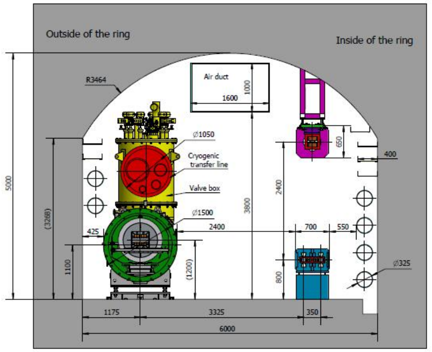


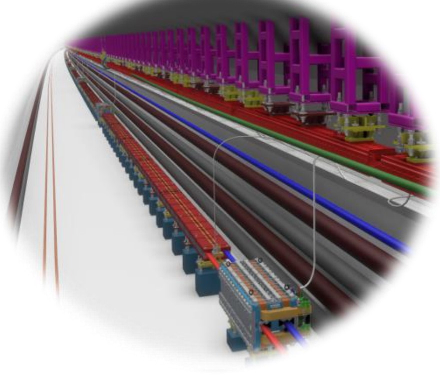
CEPC collider ring (100km)

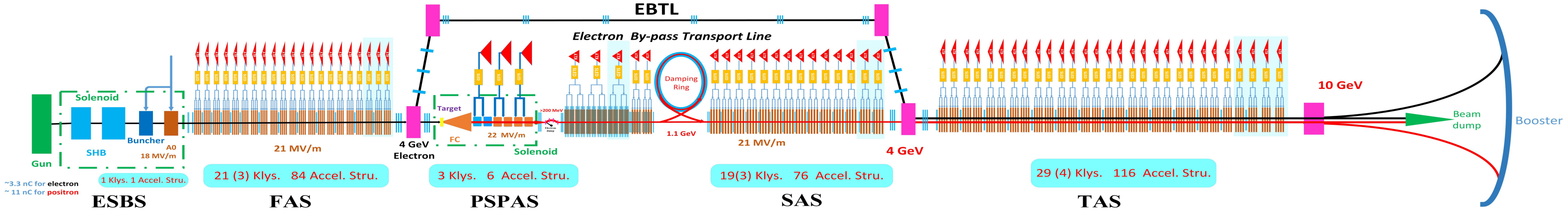


CEPC booster ring (100km)









CEPC Linac injector (1.2km, 10GeV)

CEPC CDR Parameters

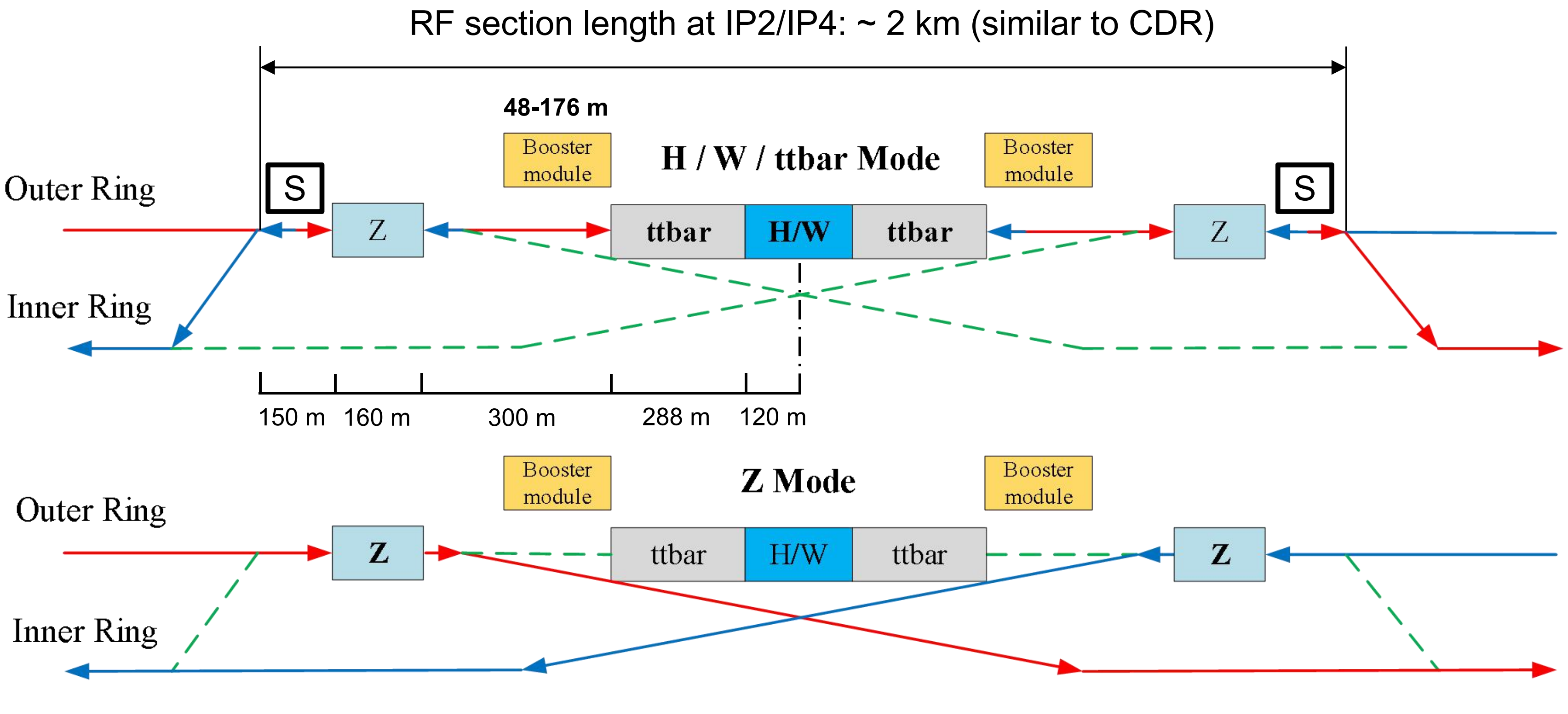
	Higgs	*W*	*Z* (3T)	*Z* (2T)
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

CEPC High Luminosity Parameter after CDR

	Higgs (high_lum.)	*Z (high_lum.)*
Number of IPs	2	2
Beam energy (GeV)	120	45.5
Circumference (km)	100	100
Synchrotron radiation loss/turn (GeV)	1.8	0.036
Crossing angle at IP (mrad)	16.5	16.5
Piwinski angle	4.87	18.0
Number of particles/bunch N_e (10^{10})	16.3	16.1
Bunch number (bunch spacing)	214 (0.7us)	10870 (27ns)
Beam current (mA)	16.8	841.0
Synchrotron radiation power /beam (MW)	30	**30**
Bending radius (km)	10.2	10.7
Momentum compact (10^{-5})	7.34	2.23
β function at IP β_x* / β_y* (m)	0.33/0.001	0.15/0.001
Emittance e_x/e_y (nm)	0.68/0.0014	0.52/0.0016
Beam size at IP σ_x/σ_y (μm)	15.0/0.037	8.8/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.115	0.0048/0.129
RF voltage V_{RF} (GV)	2.27	0.13
RF frequency f_{RF} (MHz)	650	650
Natural bunch length σ_z (mm)	2.25	2.93
Bunch length σ_z (mm)	4.42	9.6
HOM power/cavity (kw)	**0.48 (2 cell)**	**3.2 (1cell)**
Energy spread (%)	0.19	0.12
Energy acceptance requirement (%)	1.7	1.4
Energy acceptance by RF (%)	2.5	1.5
Beamstruhlung lifetime /quantum lifetime (min)	41	-
Lifetime (hour)	21	1.8
Luminosity/IP L ($10^{34}cm^{-2}s^{-1}$)	**5.0**	**101.1**

* High luminosity Z's lattice is same as Higgs CDR lattice. but high luminosity Higgs has a new lattice than that of CDR

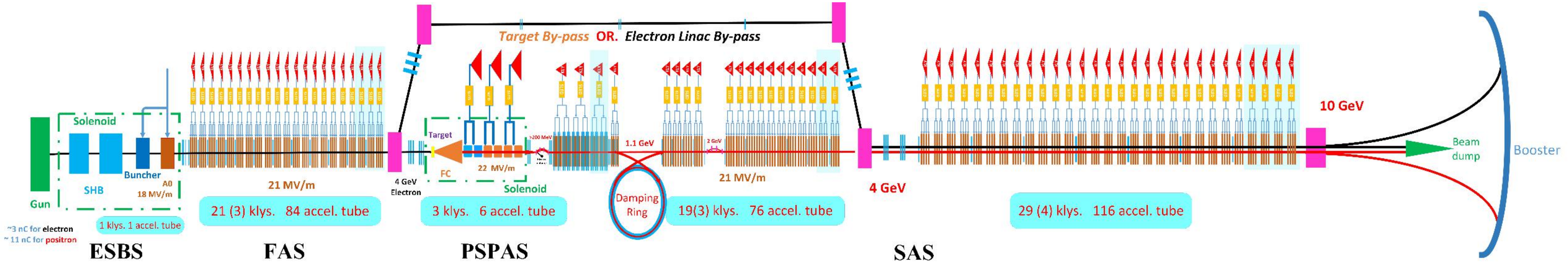
New RF Section Layout for CEPC



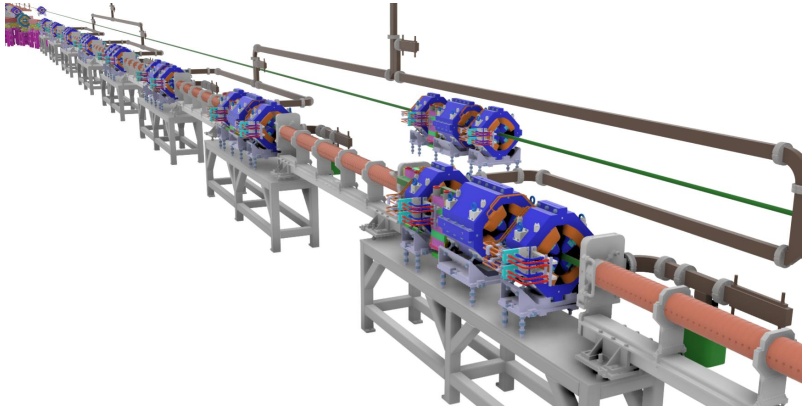
Could have 80 more separate 1-cells (thus 40 less 2-cells) for W and further Z optimization while keep the total cell number for a reasonable H cavity gradient. If consider ttbar switch to other modes, more bypass is needed. Booster bypass?

- H/W/tt use common cavities (2-cell for H/W, 5-cell for tt) for two beams. (Less than) Half filled to avoid collision in RF section. If fully filled, bunch spacing should be more than 4 km (< 25 bunches per beam).
- Z uses separate high current 1-cell cavities for two beams and **by-pass** H/W/tt cavities.
- Allow **seamless mode switching** with **unrestricted performance** of each mode until the power limit (**baseline and upgrade**). Low risk.
- A few percent more cost to **unleash CEPC potential** and **more flexible operation**.

CEPC Linac Injector (CDR)



Parameter	Symbol	Unit	Baseline	Design reached
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	**10**	**10**
Repetition rate	f_{rep}	Hz	**100**	**100**
e^-/e^+ bunch population	N_{e-}/N_{e+}		$> 9.4\times10^9$	**1.9×10^{10} / 1.9×10^{10}**
		nC	**> 1.5**	**3.0**
Energy spread (e^-/e^+)	σ_e		**$< 2\times10^{-3}$**	**1.5×10^{-3} / 1.6×10^{-3}**
Emittance (e^-/e^+)	ε_r	nm· rad	**< 120**	**5 / 40 ~120**
Bunch length (e^-/e^+)	σ_l	mm		**1 / 1**
e^- beam energy on Target		GeV	4	**4**
e^- bunch charge on Target		nC	10	**10**



CEPC Accelerator R&D Priority

1) CEPC 650MHz 800kW high efficiency klystron (80%) (No commercial products)

2) High precision booster dipole magnet (critical for booster operation)

3) CEPC 650MHz SC accelerator system, including SC cavities and cryomules

4) Collider dual aperture dipole magnets and dual aperture qudrupoles

5) Vacuum chamber system

6) SC magnets including cryostate

7) MDI mechanic system

8) Collimator

9) Linac components

10) Civil engineering design

11) Plasma injector

12) 18KW@4.5K cryoplant (Company)

…

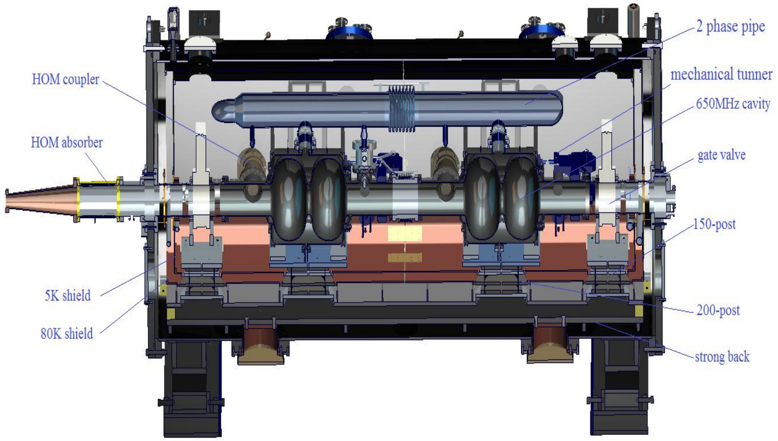
SppC technology R&D

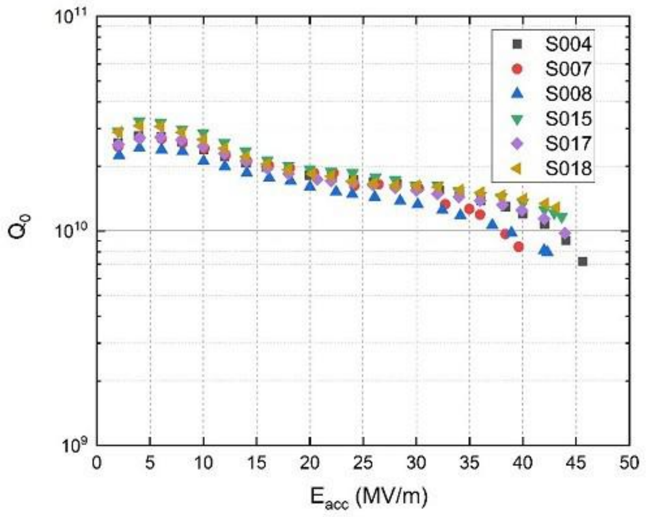
Ion based supercondcuting materials and high field magnets

CEPC SCRF R&D Progresses

CEPC 2*2cell 650MHz cryomodule with beam test later

SC cavity vertical test temperature monitor system established





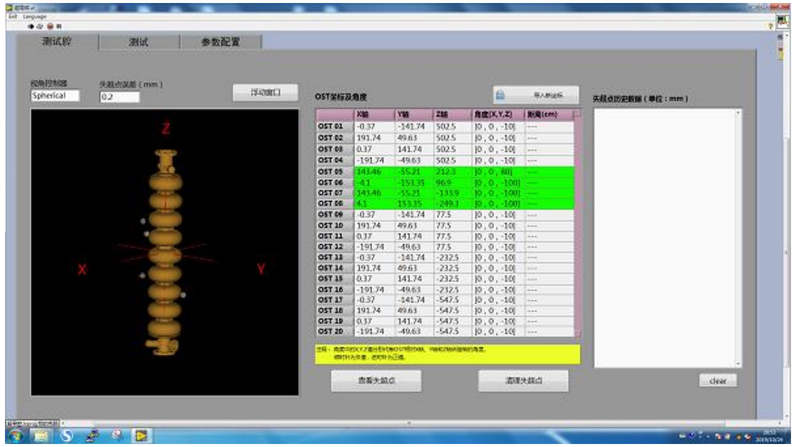
1.3GHz fine grain single cell:

1) 45.6MV/m

2) 43MV/m@Q01.3×10^{10}

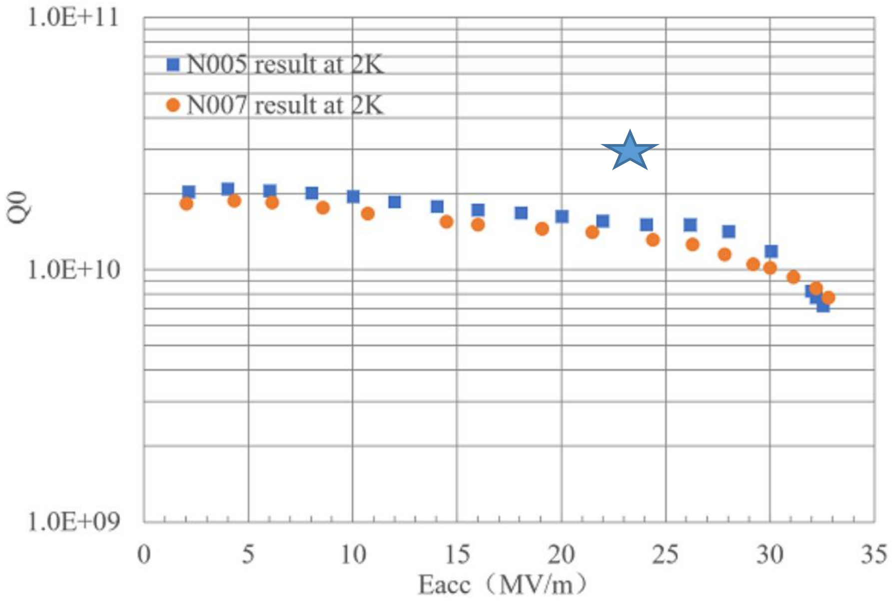
(2020-12-25 at IHEP)

General superconducting cavity test cryomodule in IHEP New SC Lab

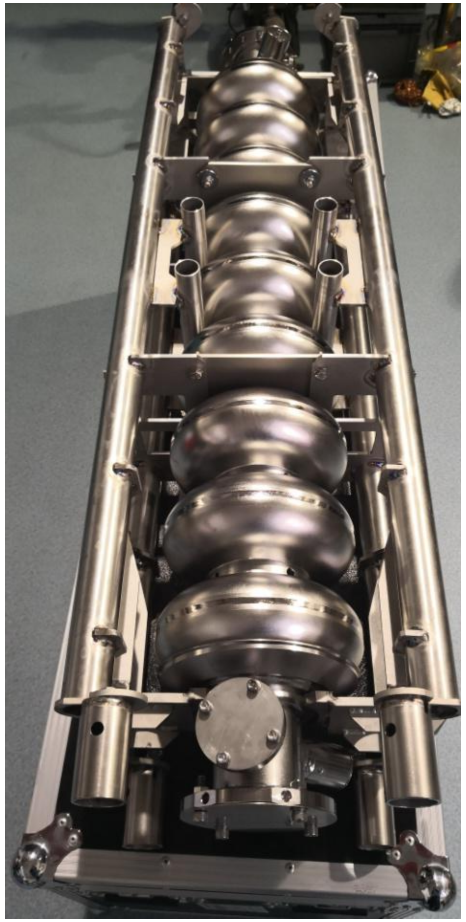


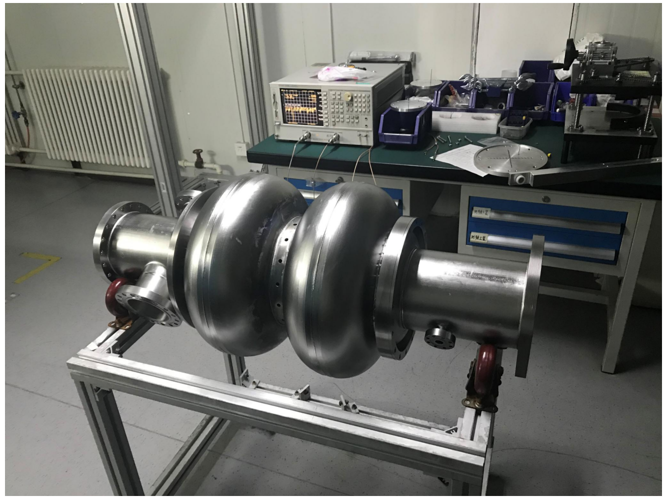
General superconducting cavity test cryomodule in IHEP New SC Lab

IHEP 650MHz 2cell and 1.3 GHz 9-cell Cavities

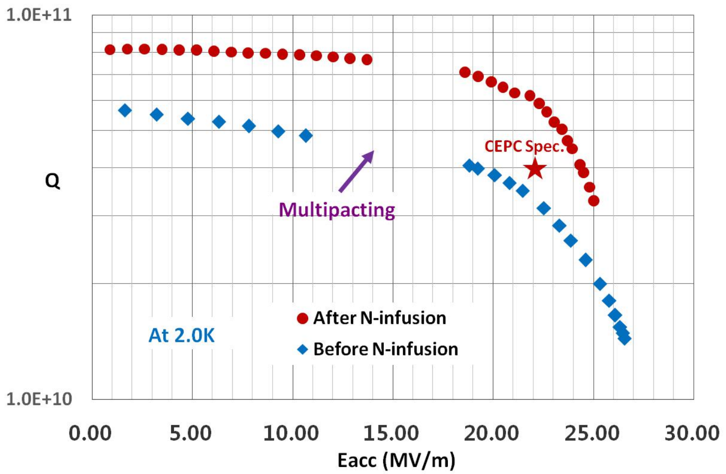


Booster 1.3GHz 9 cell cavity



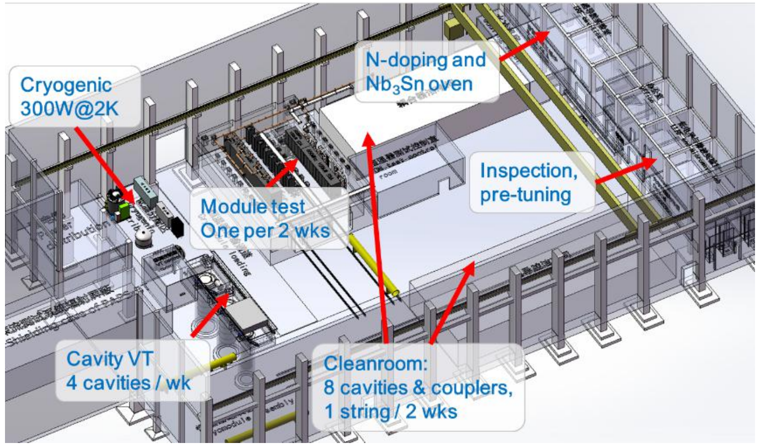


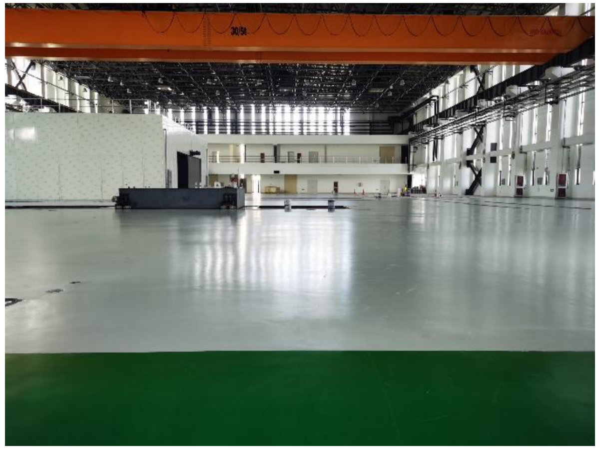
Collider ring 650Mhz 2 cell cavity



650 MHz 2-cell cavity reached **6E10@22MV/m** after N-infusion, which has exceeded CEPC Spec （**Q=4E10@Eacc=22MV/m**）.

IHEP New SC Lab under Construction (Status in Nov. 2019)





New SC Lab Design (4500m^2)

SC New Lab will be available in 2021

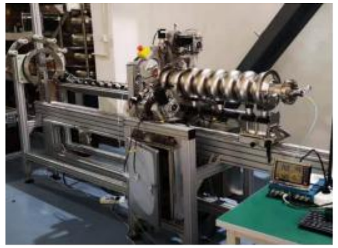
Crygenic system hall in Jan. 16, 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

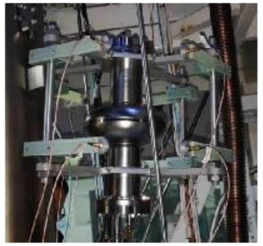
Nb/Cu sputtering device

Cavity inspection camera and grinder

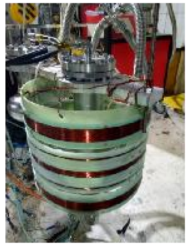


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

Vertical test dewars

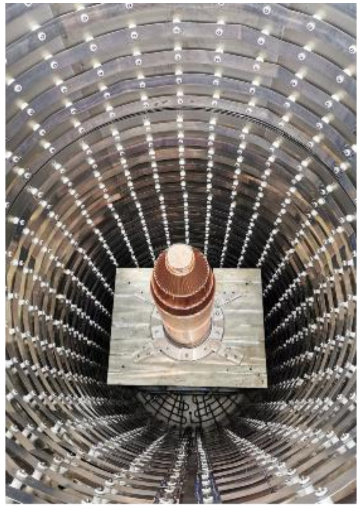
Horizontal test cryostat

CEPC 650MHz High Efficiency Klystron Development

Established "High efficiency klystron collaboration consortium", including IHEP & IE(Institute of Electronic) of CAS, and Kunshan Guoli Science and Tech.

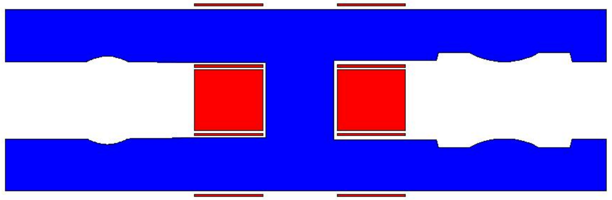
- 2016 – 2018： Design conventional & high efficiency klystron
- 2017 – 2018： Fabricate conventional klystron & test
- 2018 - 2019： Fabricate 1st high efficiency klystron & test
- 2019 - 2020： Fabricate 2nd high efficiency klystron & test
- 2020 - 2021： Fabricate 3rd high efficiency klystron & test

Parameters	Conventional efficiency	**High efficiency**
Centre frequency (MHz)	650+/-0.5	**650+/-0.5**
Output power (kW)	800	**800**
Beam voltage (kV)	80	**-**
Beam current (A)	16	**-**
Efficiency (%)	~ 65	**> 80**

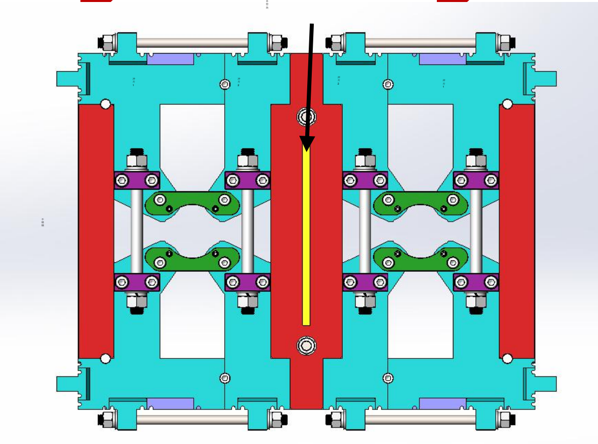


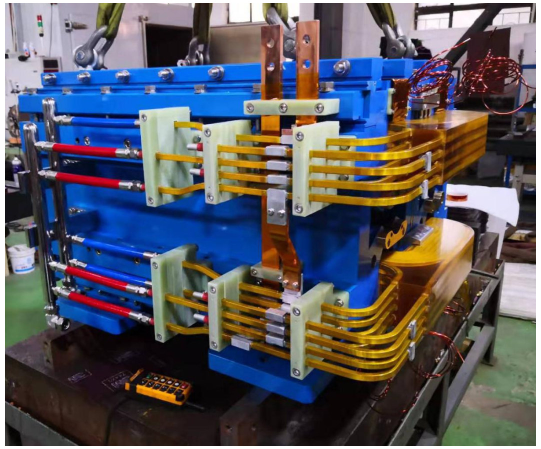
On March 10， 2020， the first CEPC650Mhz klystron output power has reached pulsed power of 800kW (400kW CW due to test load limitation), efficiency 62% and band width>+-0.5Mhz.

CEPC Collider Ring dual Aperture Dipole, Quadrupole and Sextupole Magnet Design Progress

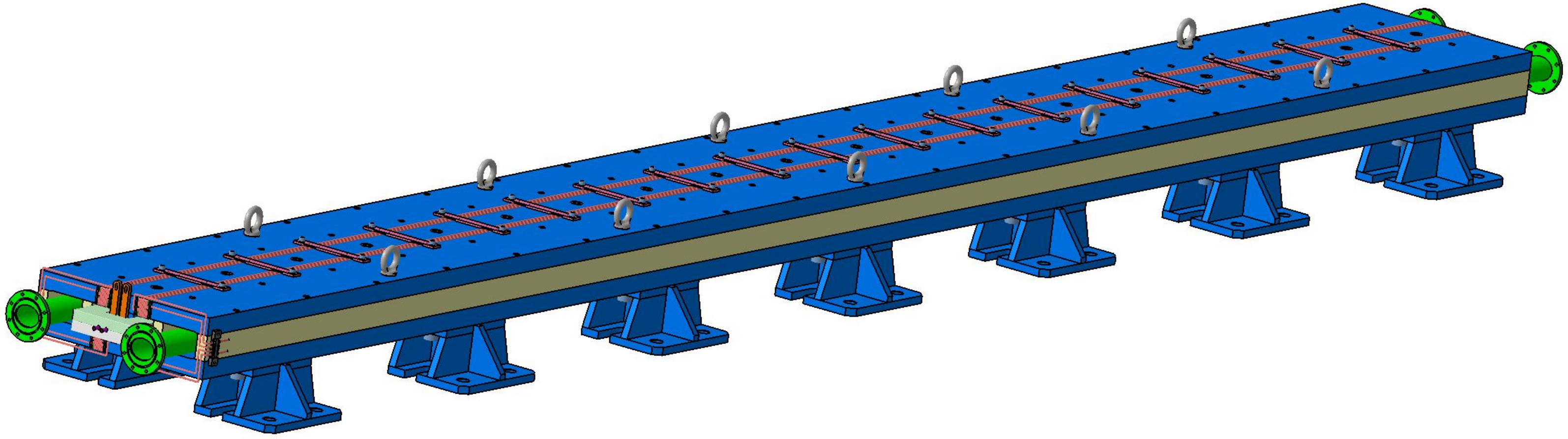


First dual aperture dipole test magnet of 1m long has been fnished in Nov, 2019





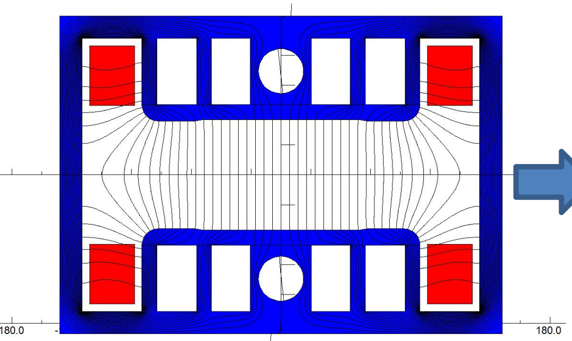
First dual aperture quadrupole magnet has been fnished in Nov, 2019

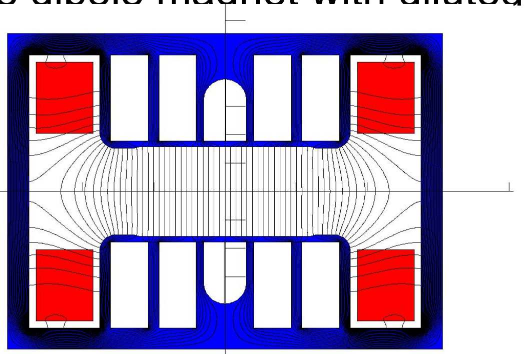


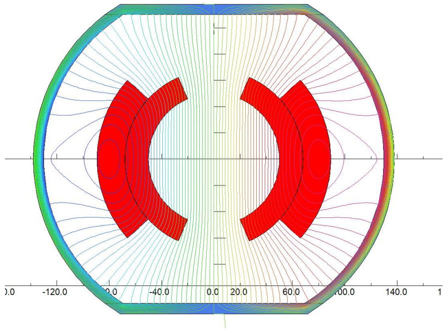
The mechanical design of a full size CEPC collider ring dual aperture dipole of 5.7m long has been designed and be fabricated at the end of 2020.

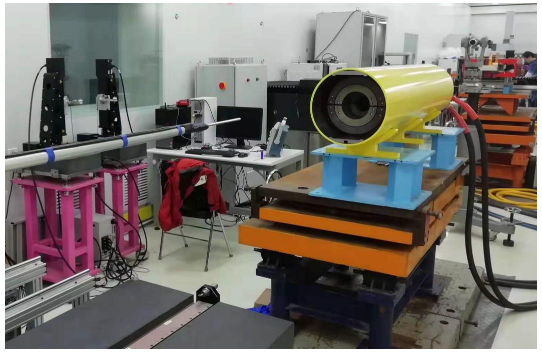
Booster High Precision Low Field Dipole Magnets

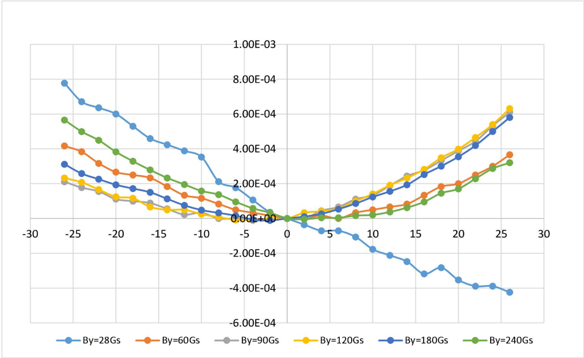
Two kinds of the dipole magnet with diluted iron cores and without iron core (CT) are proposed and designed



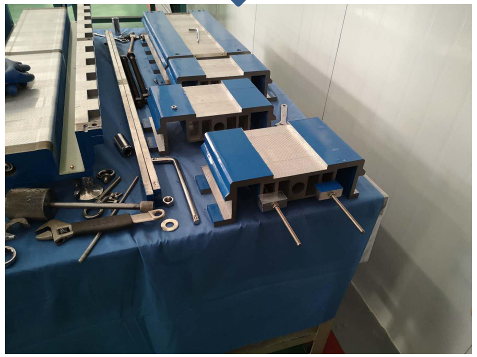




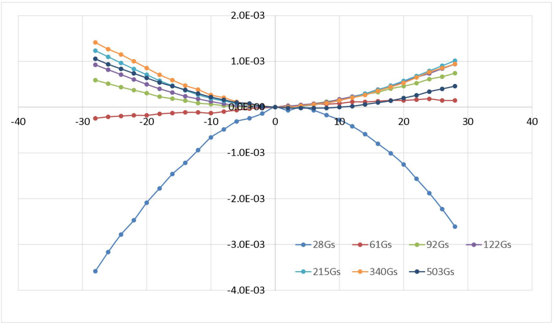




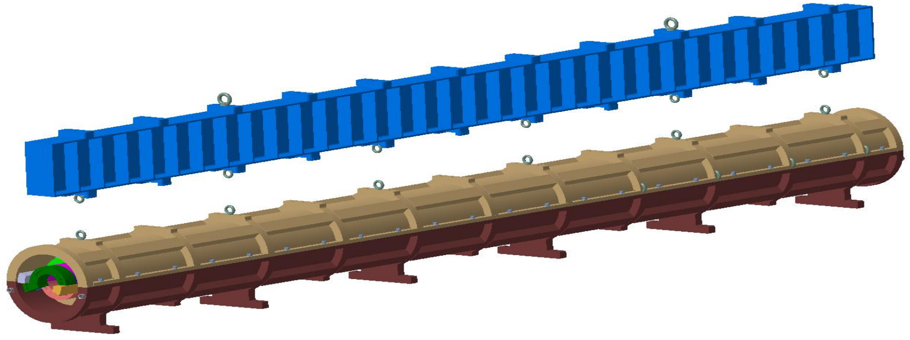
1m long CT test booster dipole magnet without iron core completed in Oct. 2019, and the test result shows that CT design reached the design goal.



The improved model is under test



The first 1m long test booster dipole magnet with iron core, completed in Nov. 2019, and not yet reached design goal, improvement is under way



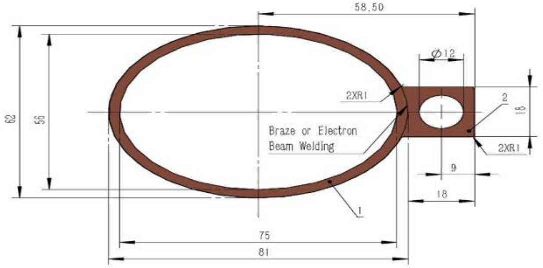
A full scale CT dipole magnet of 5.1m long is under design, and fabrication will be completed at te end of 2020

CEPC Vacuum System R&D

NEG coating suppresses electron multipacting and beam-induced pressure rises, as well as provides extra linear pumping. Direct Current Magnetron Sputtering systems for NEG coating was chosen.

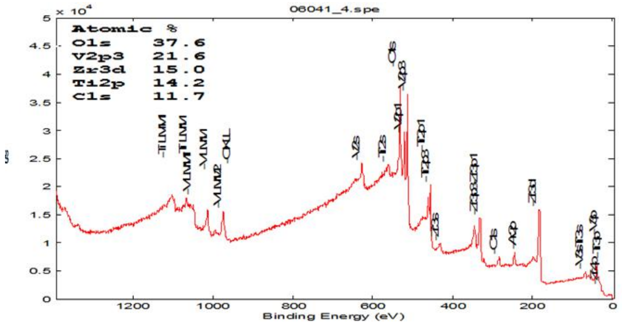
- The vacuum pressure is better than 2 x 10-10 Torr
- Total leakage rate is less than 2 x 10-10 torr.l /s.

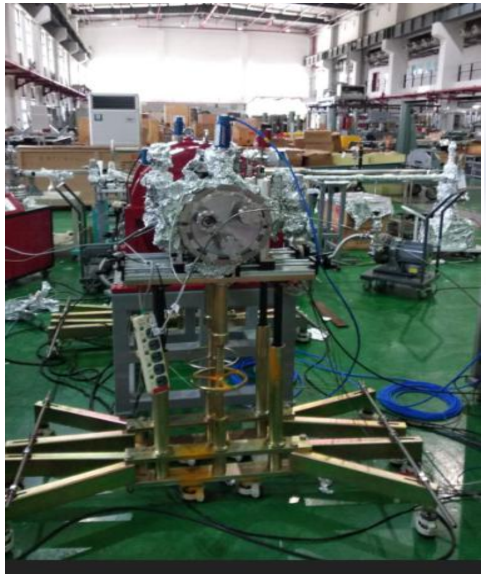
Positron ring

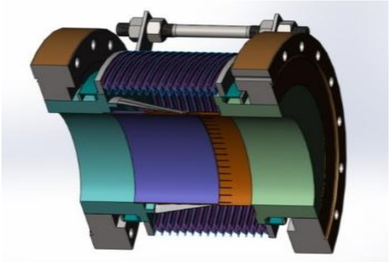


Copper vacuum chamber (Drawing) elliptic 75×56, thickness 3, length 6000)

Two 6m long vacuum chambers both for copper and aluminum







SPPC Parameter Choice and Comparation

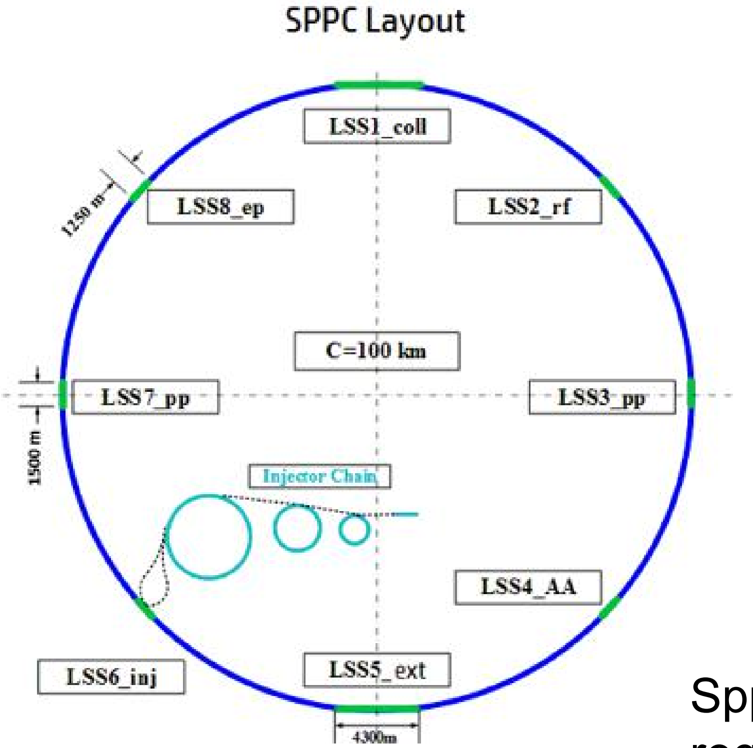
CDR

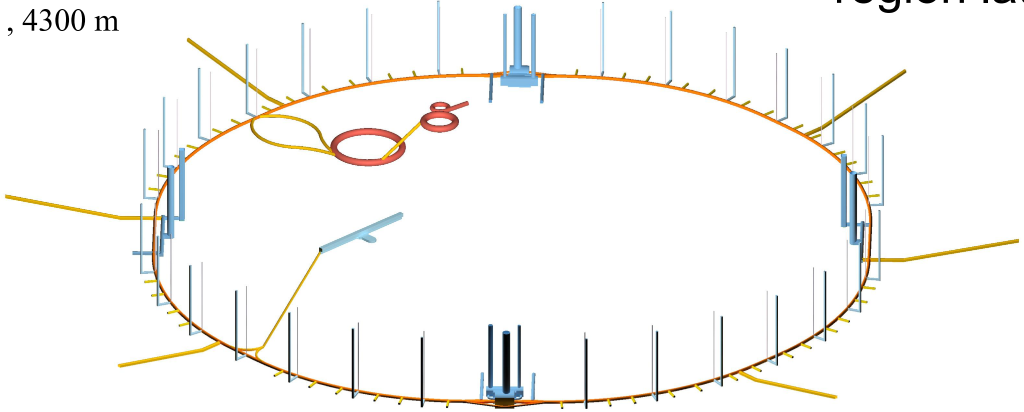
Table 2: SPPC Parameter list(2017.1)[4.6]

	SPPC (Pre-CDR)	SPPC 61Km	SPPC 100Km	SPPC 100Km	SPPC 82Km	SPPC phase 1	SPPC phase 2
Main parameters and geometrical aspects							
c.m. Energy[E_0]/TeV	71.2	70	100.0	128.0	100.0	75.0	125.0-150.0
Circumference[C_0]/km	54.7	61.0	100.0	100.0	82.0	100.0	100.0
Dipole field[B]/T	~~20~~	~~19.88~~	~~16.02~~	~~19.98~~	~~19.74~~	~~12.00~~	~~20-24~~
Dipole curvature radius[ρ]/m	5928	5889.64	10676.1	10676.1	8441.6	10415.4	-
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8	0.8	-
Arc filling factor[f_1]	0.79	0.78	0.78	0.78	0.78	0.78	-
Total dipole length [L_{Dipole}]/m	37246	37006	67080	67080	53040	65442	-
Arc length[L_{ARC}]/m	47146	47443	86000	86000	68000	83900	-
Straight section length[L_{ss}]/m	7554	13557	14000	14000	14000	16100	-
Physics performance and beam parameters							
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.20×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}	1.01×10^{35}	-
Beta function at collision[β^*]/m	0.75	0.85	0.99	0.22	1.06	0.71	-
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0068	0.0079	0.0073	0.0058	-
Number of IPs contribut to ΔQ	2	2	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.0130	0.0136	0.0158	0.0146	0.0116	-
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024	0.768	-
Bunch separation[Δt]/ns	25	25	25	25	25	25	-
Number of bunches[n_b]	5835	6506	10667	10667	8747	10667	-
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0	1.5	-
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.59	3.11	3.35	3.16	-
RMS IP spot size[σ^*]/μm	9.0	8.85	7.86	3.04	7.86	7.22	-
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.67	16.26	69.35	15.31	22.03	-
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.13	33.10	56.19	31.03	41.76	-
RMS bunch length[σ_z]/mm	75.5	56.69	66.13	14.62	70.89	47.39	-
Full crossing angle[θ_c]/μrad	146	138.03	105.93	179.82	99.29	133.65	-
Reduction factor due to cross angle[F_{ca}]	0.8514	0.9257	0.9247	0.9283	0.9241	0.9265	-
Reduction factor due to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989	0.9989	-
Energy loss per turn[U_0]/MeV	2.10	1.98	4.55	12.23	5.76	1.48	-
Critical photon energy[E_c]/keV	2.73	2.61	4.20	8.81	5.32	1.82	-
SR power per ring[P_0]/MW	2.1	2.03	4.66	12.52	5.90	1.13	-
Transverse damping time [τ_x]/h	1.71	1.994	2.032	0.969	1.32	4.70	-
Longitudinal damping time [τ_ε]/h	0.85	0.997	1.016	0.4845	0.66	2.35	-

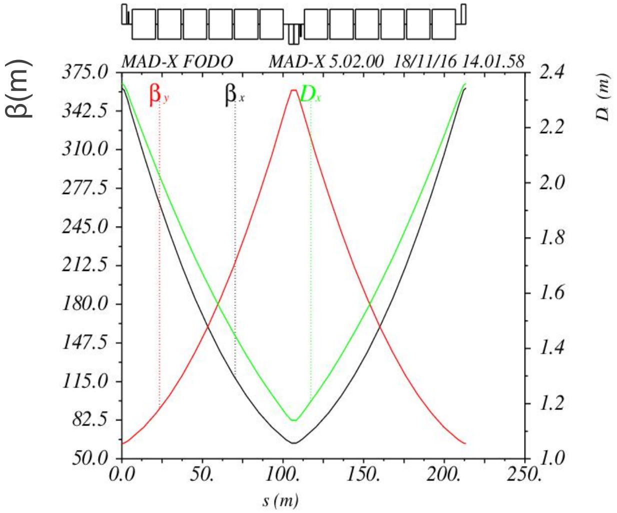
General Layout of SPPC

- Length of each section at present:
- 8 arcs, total length 83400 m
- 2 IPs for pp, 1500 m each
- 2 IRs for injection or RF, 1250 m each
- 2 IRs for ep or AA, 1250 m each
- 2 IRs for collimation(ee for CEPC ）, 4300 m each
- C = 100 km



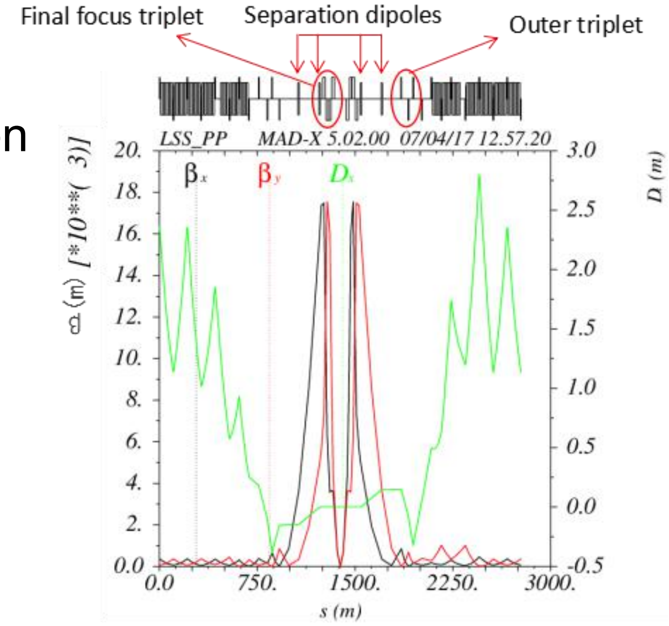


SppC ARC lattice



ARC FODO cell structure

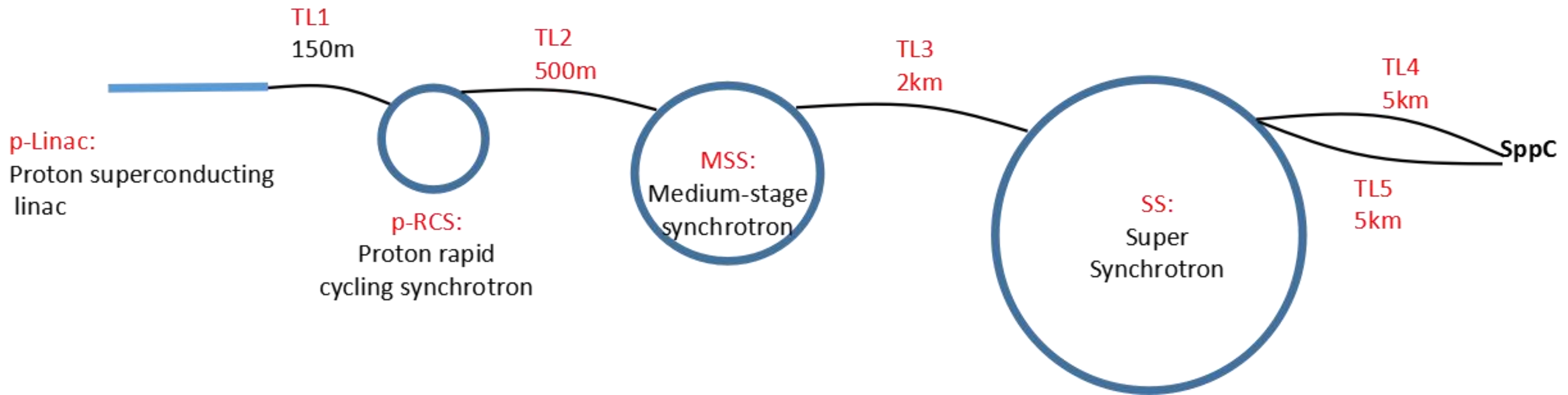
SppC interaction region lattice



LSS_PP(beta*=0.75 m)

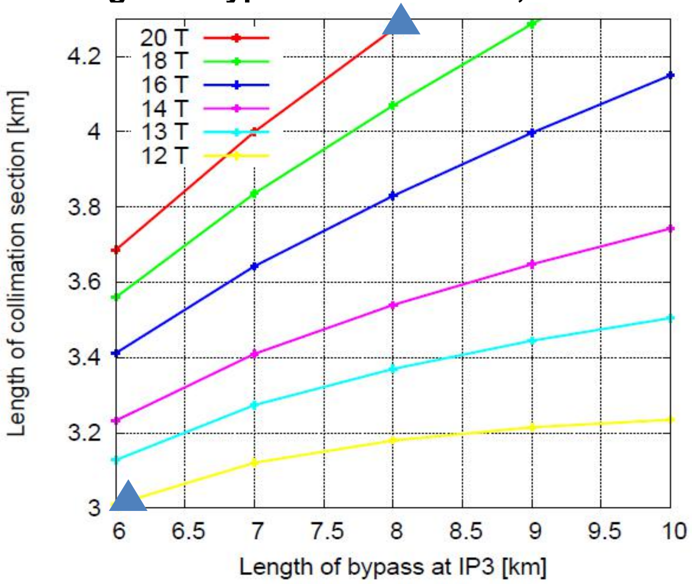
SppC Injector Chain

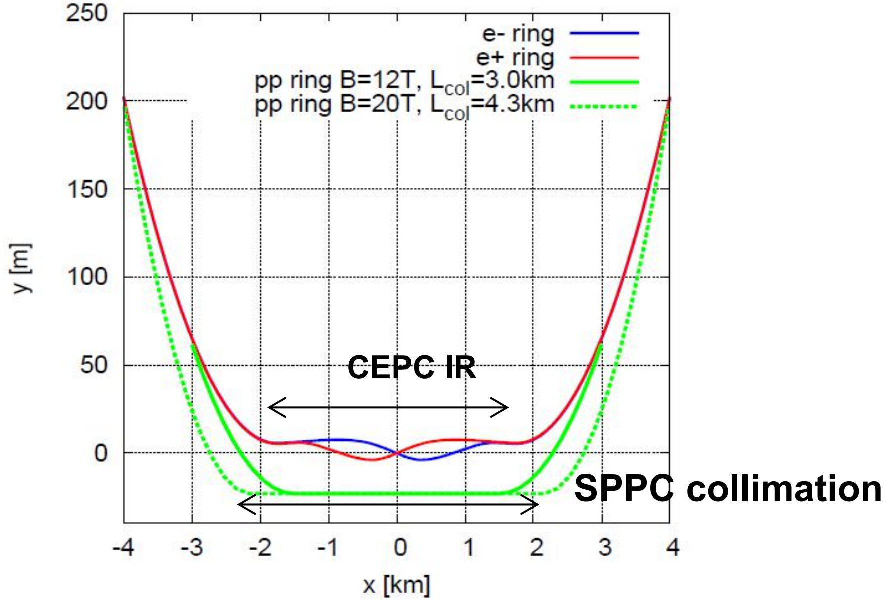
	Value	Unit		Value	Unit
p-Linac			MSS		
Energy	1.2	GeV	Energy	180	GeV
Average current	1.4	mA	Average current	20	uA
Length	~300	m	Circumference	3500	m
RF frequency	325/650	MHz	RF frequency	40	MHz
Repetition rate	50	Hz	Repetition rate	0.5	Hz
Beam power	1.6	MW	Beam power	3.7	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.34	mA	Accum. protons	1.0E14	
Circumference	970	m	Circumference	7200	m
RF frequency	36-40	MHz	RF frequency	200	MHz
Repetition rate	25	Hz	Repetition period	30	s
Beam power	3.4	MW	Protons per bunch	1.5E11	
			Dipole field	8.3	T



Compatibility of CEPC and SppC at the IP1 and IP3

- The compatibility at the IP1 and IP3 need to be fixed
  - **A long section of SPPC at IP1 and IP3 is used for combining the transverse and momentum collimation in the same section.**
  - SPPC locates outside and is longer than CEPC at this region (SPPC 4.3km, CEPC 3.32km)
  - Geometry of CEPC kept, adjust the SPPC's
- No solutions of bypass with collimation=4.3km, B=12 T
  - **Solutions can be found with stronger bends or shorter collimation sections which means a different design of SPPC collimation section**





CEPC-SppC compatibility relation between collimation section length and SppC dipole maximum field has been found! CEPC and SppC could be compatible in the same tunnel

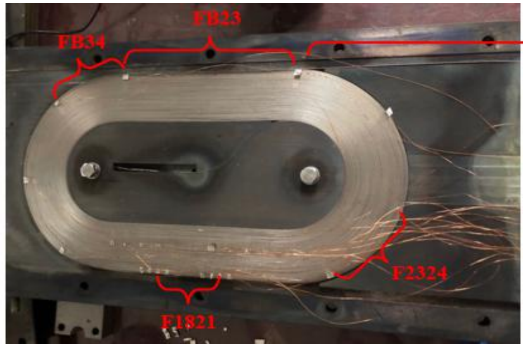
Status of the High Field Dipole Magnet R&D-2

Test of the 1st IBS solenoid coil at 24 T and the 1st IBS racetrack coil at 10 T

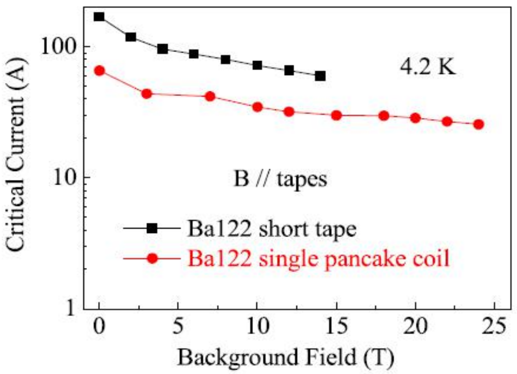
Table 2. Specification of single pancake coil

Parameter	Unit	Value
Inner diameter	mm	30
Outer diameter	mm	34.8
Height	mm	4.62
Thickness of stainless steel tape	mm	0.1
Turns		4.5
Total length of IBS wire	mm	450

Very good performance!



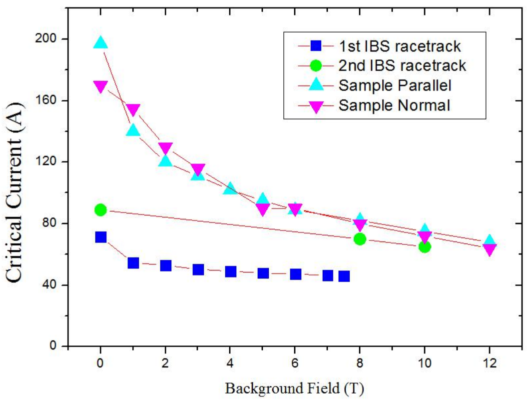
25T-HM, RT bore Φ38 mm



Supercond. Sci. Technol. 32 (2019) 04LT01

Demonstrating that IBS are very promising for high-field magnet applications

Critical Current w.r.t Background Field of IBS Racetracks

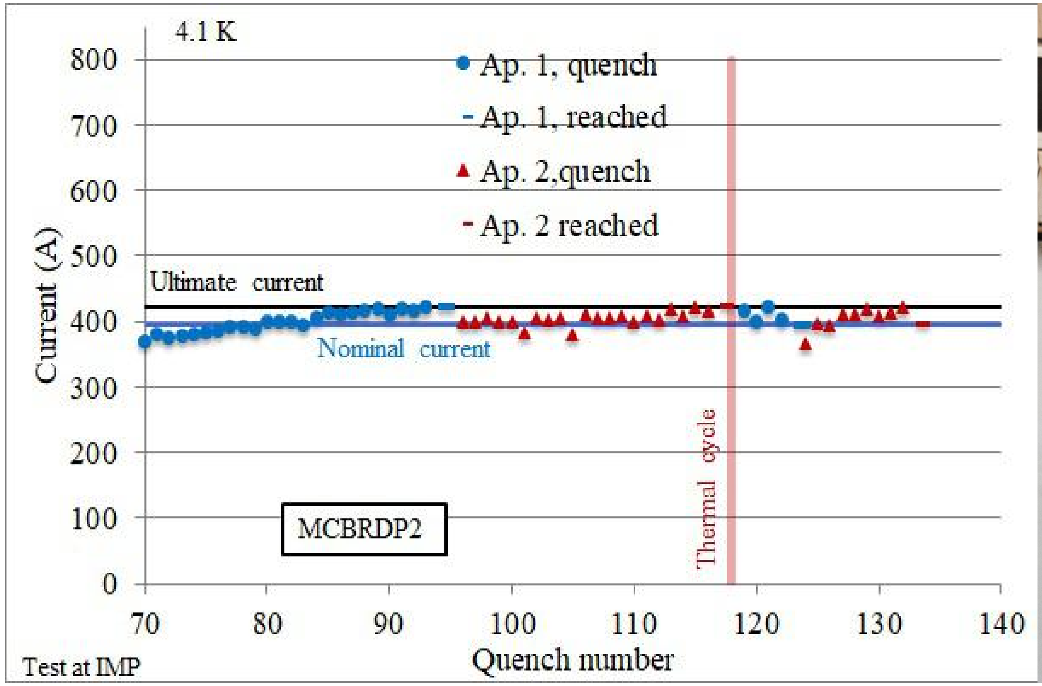


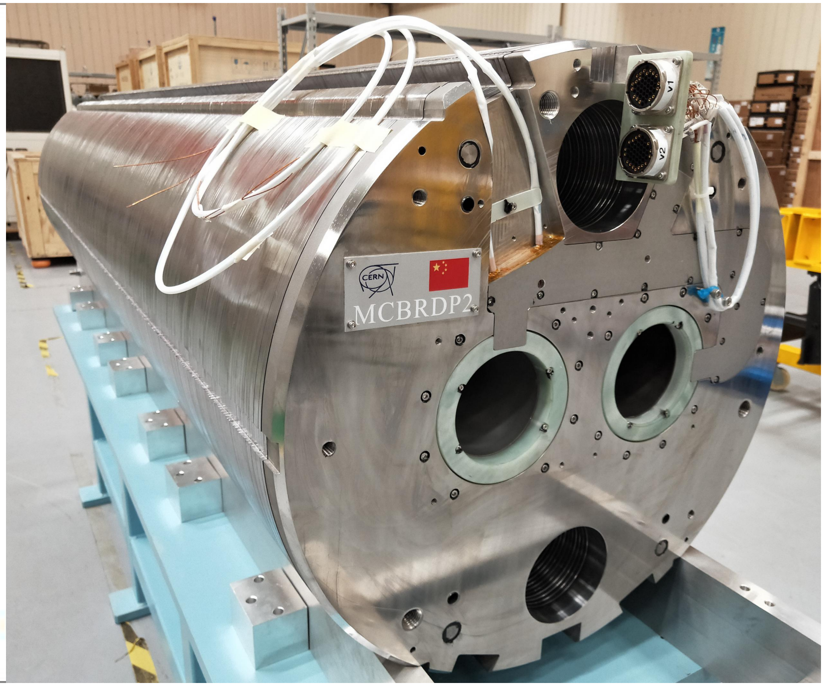
Supercond. Sci. Technol. 2020, in press

China-CERN HL-LHC CCT Project

China will provide 12+1 units CCT superconducting magnets for the HL-LHC project

After more than 1 month test and training at 4.2K, both apertures reached the design current and ultimate current, and the field quality is within the limit.





<u>The 1st prototype CCT magnethas been sent to CERN. A good start for the 12 units series production.</u>

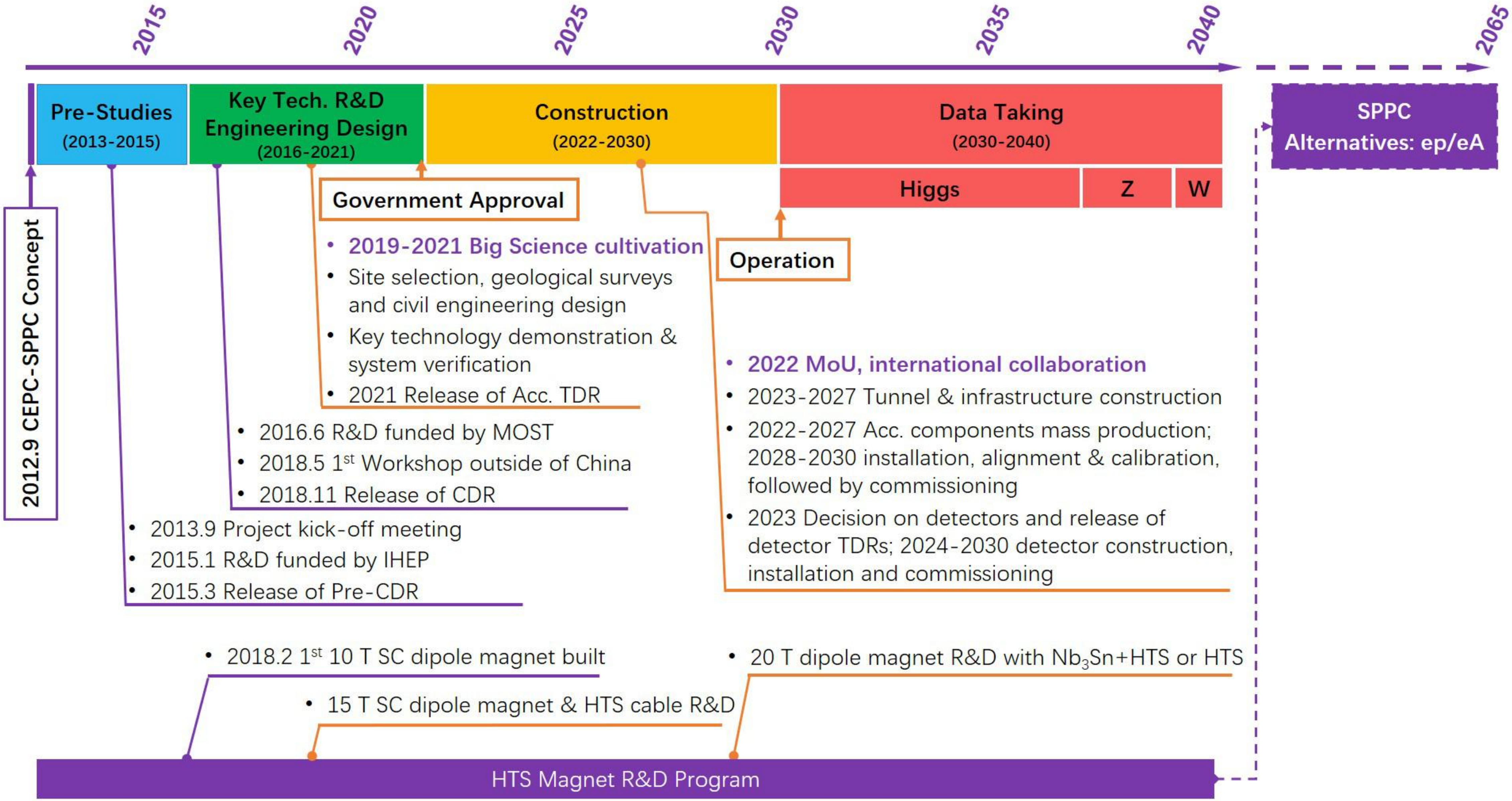
CEPC Industrial Promotion Consortium (CIPC) Collaboration Status

Established in Nov. 7 , 2017
CIPC Annual Meeting, July 26 , 2018

1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Vacuum technologies
7) Electronics
8) SRF
9) Power sources
10) Civil engineering
11) Precise machinary.....

Now:
-Huanghe Company, Huadong Engineering Cooperation Company, on CEPC civil engineering design, site selection, implementation...
-Shenyang Huiyu Company on CEPC MDI mechanical connection design
-Zhongxin Heavy Industry on Elecletric-magnetic seperator design
-China Astronotics Department 508 Institute on CEPC MDIsupporting design and CEPC magnets mechanical designs...
-Kuanshan Guoli on CEPC 650MHz high efficiency klystron
-Huadong Engineering Cooperation Company, on CEPC alignement and installation logistics...

CEPC Project Timeline



CEPC submissions to Snowmass21

CEPC Input to the ESPP 2018

-Accelerator

LOI

CEPC Accelerator Study Group

Executive summary

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for a large-scale accelerator. Due to the low mass of the Higgs, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with reasonable luminosity, technology, cost and power consumption. The Higgs boson is a crucial cornerstone of the Standard Model (SM). It is at the center of some of its biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, and many other related questions. Precise measurements of the properties of the Higgs boson serve as excellent tests of the underlying fundamental physics principles of the SM, and they are instrumental in explorations beyond the SM. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies. The tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies beyond the LHC.

The CEPC is a large international scientific project initiated and hosted by China. It was presented for the first time to the international community at the ICFA Workshop "*Accelerators for a Higgs Factory: Linear vs. Circular*" (HF2012) in November 2012 at Fermilab. A Preliminary Conceptual Design Report (Pre-CDR, the *White Report*)[1]was published in March 2015, followed by a Progress Report (the *Yellow Report*)[2] in April 2017, where CEPC accelerator baseline choice was made. The Conceptual Design Report (CEPC Accelerator CDR, the *Blue Report*) [3]has been completed in July 2018 by hundreds of scientists and engineers after international review from June 28-30, 2018 and formally released on Sept 2, 2018.

Including SppC and siting

CEPC -Accelerator Technologies to Snowmass2021 AF7

CEPC Accelerator Study Group

Executive summary

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for a large-scale accelerator. Due to the low mass of the Higgs, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with reasonable luminosity, technology, cost and power consumption. The Higgs boson is a crucial cornerstone of the Standard Model (SM). It is at the center of some of its biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, and many other related questions. Precise measurements of the properties of the Higgs boson serve as excellent tests of the underlying fundamental physics principles of the SM, and they are instrumental in explorations beyond the SM. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies. The tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies beyond the LHC. The CEPC Preliminary Conceptual Design Report (Pre-CDR, the *White Report*)[1]was published in March 2015, followed by a Progress Report (the *Yellow Report*)[2] in April 2017, where CEPC accelerator baseline choice was made. The Conceptual Design Report (CEPC Accelerator CDR, the *Blue Report*) [3] has been publically realsed in Nov. 2018, and also submitted to European High Energy Strategy in May, 2019 [4].

Technologies

Collider Design
SCRF
Klystron
Linac+plasma
accelerator injector
Cost

*Both documentshave been submitted by J. Gao, IHEP, gaoj@ihep.ac.cn

Summary

- CEPC R&D efforts towards TDR progress well with such as klystron, SCRF, magnets, vacuum system, etc. with the aim to complet TDR before 2023
- SppC high field SC magnets R&D and LHC-HL CCT magnets fabrication were carried out
- CEPC international collaboration and collaboration with industries go well
- **CEPC LOI** for **AF** of Snowmass21 has been submitted and online on June 29, 2020 at: https://www.snowmass21.org/docs/files/?dir=summaries/AF
- **CEPC Accelerator Technologies** Documents to Snowmass2021 **AF7** has been submitted on July 21, 2020

Thanks go to CEPC-SppC team, CIPC and international partners and colleageus